DOCUMENT RESUME

ED 092 364 SE 017 730

AUTHOR Howe, Ann
TITLE Formal Operational Thought and the High School Science Curriculum.
PUB DATE Apr 74
NOTE 19p.; Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (47th, Chicago, Illinois, April 1974)

EDRS PRICE MF-$0.75 HC-$1.50 PLUS POSTAGE
DESCRIPTORS *Cognitive Measurement; *Concept Formation; Curriculum; *Learning Processes; Literature Reviews; Mathematics Education; Science Education; Secondary School Science; Thought Processes
IDENTIFIERS Piaget (Jean)

ABSTRACT

This review was undertaken to determine whether there is evidence to support the reality of a stage of Formal Operational Thought, whether there is agreement as to the Age of Acquisition of it, and the effect of schooling on the acquisition of the ability to perform formal operational tasks. An extensive review of the literature, including many journals outside the field of education, was carried out. Results of the study include: (1) there is very little evidence for a Unitary Stage of Formal Operational Thought; (2) since this is so, it was considered impossible to define an age of acquisition of Formal Operational Thought; (3) there is evidence to show that schooling has an effect on the age at which subjects become able to perform formal operational tasks; and (4) specific science curricula do not seem to effect change in performance on formal operational tasks. The results of the review of literature suggest that the idea of one stage of Formal Operational Thought may not be useful in the attempt to understand adolescent thought and to design high school science curricula. (Author/EB)

ED 092364

FORMAL OPERATIONAL THOUGHT AND THE HIGH SCHOOL SCIENCE CURRICULUM

Ann Howe
Center for Science Education
Syracuse University

I. INTRODUCTION

The ability to solve certain types of problems and perform certain cognitive tasks marks the transition from childhood to adolescence in Piagetian theory. The theory proposes that between the ages of 11 and 14 adolescents enter into a stage of formal operational thought in which it becomes possible for them to reason with propositions and hypotheses by using the operations of formal logic.

The transition from concrete to formal operations is the subject of The Growth of Logical Thinking from Childhood to Adolescence, written by Piaget in collaboration with Barbel Inhelder and first published in English in 1958. (The French edition was published in 1955.) The book brings together the empirical findings of Inhelder and the theoretical formulations of Piaget. The former consist of the results of presenting to children and adolescents 15 problems which require advanced reasoning for their solution. The theoretical sections contain Piaget's analysis of the tasks and an explication of the mechanisms of their solutions in terms of the 16 binary propositions of formal logic. The formal operational stage is called Stage III and is divided into substage IIIA, at which stage Piaget and Inhelder found adolescents from 11-12 to 14-15 years, and substage IIIB, which adolescents were found to enter at 14 to 15. Tasks which require formal operational thought had been described earlier in The Child's Conception of Geometry (Piaget, Inhelder, and Szeminska), published in France in 1948 and in Great Britain in 1952, but the theoretical aspects were not fully elaborated at that time.

The present review was undertaken to determine whether there is a body of evidence to support the reality of a stage of formal operational thought,

---

Paper presented for discussion at the annual meeting of the National Association for Research in Science Teaching, Chicago. April, 1974.

to examine the data on the factors associated with intellectual development during adolescence, and to consider what the implications of these might be for curriculum and teaching methods in secondary school science.

II. THE THEORY

In Piagetian theory there are four phases of growth which characterize intellectual development: the sensorimotor stage, the preoperational stage, the stage of concrete operations, and the stage of formal operations. In this context an operation is a "reversible, internalizable action which is bound up with others in an integrated structure...(It) is a means for mentally transforming data about the real world so that they may be...used in the solution of problems" (Piaget and Inhelder, 1958, pp. xiii-xiv). An operation may be carried out externally, in the manipulation of categories (concrete) or propositions (formal). Concrete operations are mental actions which organize observed or experienced reality and do not necessarily involve the actual manipulation of tangible objects. For example, the addition of arithmetic numbers is a concrete operation (Adler, 1966). An operation differs from the simple action or goal-directed behavior of the preoperational child in that it is internalized and reversible; that is, the action which had to be carried out externally by the preoperational child can be carried out internally ("in the head") by the concrete operational child, and the child understands that the result of an action can be reversed by reversing the action. A child in the concrete operations stage who puts a weight on a balance and sees that the scale tips too far in one direction can take such corrective action as searching for a lighter weight on the basis of an internal mental structure. He is no longer dependent on trial and error as a means of solving problems.

As the child grows and his ability for logical thinking develops he uses concrete operations with increasing facility and on more complex problems

However, when he is confronted with a problem in which he must isolate one variable and hold one or more other variables constant, or in which he must think of all the possible combinations and systematically exclude some of them, his thought system (i.e., the structure of concrete operations) is inadequate; he cannot solve the problem until he is able to reason with propositions and hypotheses. The ability to consider the possible as well as the given and to use combinatorial analysis in solving problems distinguishes formal from concrete operational thought.

III. RESEARCH RELATED TO THEORY

Piaget has been criticised from the beginning for his attempt to equate the operations of formal logic with the mental structure of an adolescent (or an adult). Parson (1960), a logician, argues that Piaget is not consistent in his use of the terms of logic, that his argument is very hard for a logician to follow and that, in effect, the idea doesn't make sense. More recently, two logicians and a clinical psychologist (Bynum, Thomas and Weitz, 1972) systematically examined the protocols in The Growth of Logical Thinking for evidence that all 16 of the binary operations of formal logic were, in fact, used by the subjects in solving Inhelder's problems. They could identify only eight of the operations, did not find all 16 operations to be necessary for solving the problems, and believe it is highly unlikely that adolescents use all 16 operations. They report that they could not, in their discussions, teaching, or in any other way express 6 of the 16 operations in everyday language. Lovell (1961) who has replicated and extended Piaget's work in many areas of mathematics, has, nevertheless, called Piaget to task for forcing adolescent thinking into an inappropriate logical model. Finally, Lunzer, who stated in an earlier work (1965) that he did not believe that the logic of the four-group was psychologically fundamental to formal operations, stated more recently (1973) that he is now even more convinced that formal logic is not a good descriptor or model for the mental structure which is formed during adolescence.

Another aspect of the theory which has received much attention is Piaget's use of the concept of stage (Flavell and Wohlwill, 1969; Kessen, 1970; and Pinard and Laurendeau, 1969). What does it mean to say that a child has reached a certain "stage" of cognitive development? There appear to be several popular misconceptions about the concept of stage as used by Piaget and by those who work within the Piagetian framework. One misconception is that the passage from one stage to the next is sudden and abrupt. A child is said to have become "concrete operational" if he can perform one task characteristic of the stage of concrete operations and is then assumed to be able to perform other similar tasks. Another misconception is that there is a fixed order of acquisition of individual concepts within each stage. A third misconception is the idea that a child of a certain age will automatically be in a certain Piagetian stage.

None of these touch on the essential feature of a stage, which is a unifying, underlying process of reasoning, applicable to a broad range of problems or tasks. The formulation of the integrated mental structure which makes it possible for a child to perform the tasks characteristic of a stage is a gradual process which usually takes several years for completion. Thus, there is a transition period in which the child uses the new process of reasoning only occasionally and inconsistently. His responses are variable, content-bound and inconsistent. As he begins to use the new reasoning processes in some areas, there will be other areas in which he reverts to the reasoning processes and explanations of the earlier stage. These time lags in applying the operations or processes, which are referred to as "decalages", continue until the underlying structure is consolidated and can be applied to all problems, regardless of situational or content variables. At this point the structure is stabilized. Piaget's early work indicated that the component operations which make up a stage develop in unison along a broad front, but subsequent work seems to indicate that there are individual variations, not in sequence of the major stages, which are probably invariant in sequence, but in the sequence of the tasks to which a developing structure is applied.

The stage of concrete operations has received more attention than the other stages and is probably better understood. There seems to be consensus that it is reasonable to call this period a "stage"; that is, that there is evidence of a unified, underlying reasoning process which is brought to bear on a wide range of problems. The question which we come to now is whether there is sufficient evidence to say that the mental abilities which emerge in adolescence can also be said to constitute a stage.

One of the first investigators to replicate the Inhelder and Piaget experiments was Lovell (1961). He repeated ten of the experiments, testing each of 200 subjects on four of the tasks. The subjects' ages ranged from 8 to 18. Although some of the older subjects could not perform the tasks, an indication that they had not acquired formal operational ability, the strategies used by the subjects were much the same as those described by Inhelder and Piaget (1958). The results of the investigation led Lovell to conclude that the main stages in the development of logical thinking proposed by Inhelder and Piaget had been confirmed. In spite of this, he raised the question whether Piaget had forced the children's responses into a predetermined theoretical model, rather than adjusting the model to fit the response.

Lovell and Ogilvie (1961) reported the results of another study in which they replicated some of the work described in <u>The Child's Conception of Geometry</u> and concluded that Piaget was correct in placing the attainment of certain volume concepts in the formal period because concrete operations were not sufficient for the solution of the volume tasks.

Work was also done by Lunzer (1960) on the volume problem. His work confirmed the findings of Piaget, Inhelder, and Szeminska (1952) concerning the children's performance of the volume tasks but did not find support for Piaget's theoretical treatment of the basis for attainment of advanced volume concepts; i.e., the use of formal logic as a model for the reasoning process used by adolescents.

In a more important paper, Lunzer (1970) reviewed the evidence for the existence of a single process of reasoning underlying performance of all the concrete operational tasks and concluded that the evidence is in favor of affirming a unitary process for concrete operations. Then he posed the question whether there is a "parallel unity of processes underlying the further elabortions of reasoning that have been termed "formal"... and "whether Piaget is justified in postulating the existence of two successive levels in the development of logical reasoning, or whether, when the child has attained the level of 'concrete' reasoning...further progress would be a matter of quantitative gains rather than a difference in type of reasoning." (p. 595).

In order to study this problem he constructed a test composed of four groups of analogies which he thought would require for their solution the same structural complexity of thought which was necessary for the performance of Piaget's formal operational tasks. Children of ages 9 to 17 were tested. He had predicted that the 9-year-olds would be able to solve the first, and easiest, group of items, but this was not found to be the case; he was forced to conclude that even elementary analogies require something more than concrete reasoning for their solution. He suggested that the essential feature of formal reasoning is the recognition of second-order relations and that this emerges around the age of 11 or 12. Thus, his answer to the question posed at the beginning of his paper was affirmative; i.e, he thought that his work has shown that there is further structural development beyond concrete operations and that there is one underlying process which characterizes this development.

The work described above was done in the early 1960's. More recently Lunzer (1973) gave an address to the Piaget Society at a meeting in Philadelphia in which he stated that he no longer believed that there was one underlying process in formal operations but that there are, instead, several developments in reasoning beyond the level of concrete operations, and that the recognition of second-order relations which he had previously proposed as the underlying factor is inadequate to describe all of these developments. In addition to his own work, he cited the work of Peel (1971) and others. He defined four categories of tasks which represent advances in reasoning, the first acquired as early as 11 or 12 years; the last not acquired, if at all, until late in the teens. It is his view that true formal reasoning is rarely used and that neither adolescents nor most adults are very good at it. Lunzer also reiterated one point which he made in the earlier paper: that the difficulty of problems at this level cannot be measured solely or even mainly in terms of structure or form and that the content also must be taken into consideration.

Bart (1971) tested the hypothesis that formal operational skills are unifactor, using principal component and factor analysis to examine the results of testing adolescents on three tests of formal reasoning which he devised and four Piagetian formal operations tasks. He found the four tasks to be unifactor but the tests and tasks together to be bifactor.

Berzonsky (1968) carried out an experiment in which he used factor analysis in an attempt to determine whether Piaget's idea of the unitary nature of logical thinking could be supported. He did not find support for the idea but interpreted his results as indicating that there are probably at least three independent abilities involved. He suggested also that various skills and attitudes held by adolescents may be more important than "structural variations".

Another investigation which had a somewhat different outcome should also be mentioned. Brainerd (1970) carried out an experiment in which he tested children of ages 8-9, 11-12, and 14-15 on conservation of liquid volume, conservation of solid volume and density. He interpreted his results as giving evidence that concepts of volume and density both presuppose some underlying cognitive skill. Since these concepts fall very close together in time of acquisition and would probably be at the same level in Lunzer's categorization of tasks, the finding of one underlying cognitive skill, or reasoning process, in tasks so close together in the development hierarchy may not be incompatible with the findings of Lunzer and Berkowski.

In spite of some contradictory findings and differences of opinion and interpretation, the bulk of the available evidence seems to support these conclusions:

(1) There is a qualitative change in cognitive structure or reasoning ability beyond the level of concrete operations. This is to say that, however much they may be elaborated or extended, the operations of the concrete stage are not sufficient to account for the ability to perform the tasks described by Piaget and Inhelder and various tests and tasks of advanced reasoning devised by other investigators.

(2) The new structure(s) or reasoning powers do not depend on the use of all 16 of the binary operations of propositional logic. Piaget's model of adolescent thought based on the forms of logic does not stand up to scrutiny by logicians and has not proved to be very useful in helping psychologists or educators understand adolescent thinking.

(3) The development in logical thinking beyond the concrete operations level probably cannot be adequately explained by one underlying process. Piaget and Inhelder (1958) recognized this to a certain extent by describing two substages for Stage III, but the main thrust of Piaget's argument was to establish the unity of the essential process which makes possible the performance of the tasks which they used.

FACTORS ASSOCIATED WITH INTELLECTUAL DEVELOPMENT DURING ADOLESCENCE

The course of intellectual development during childhood is now much better understood than intellectual development during adolescence. All young children appear to pass through similar developmental steps in a roughly sequential way and all of them, sooner or later, develop the mental structures which allow them to use concrete operations in problem solving. The same cannot be said for adolescent mental growth and the use of formal operations. "There is ample evidence," according to Furth (1973)", that all healthy persons in all societies and ranks of life reach the stage of concrete operations. A like assertion cannot be made with equal confidence for formal thinking. Piaget is rightly cautious on this point." (p. 67).

Some of the factors which may be associated with attainment of formal operations will now be considered.

1. Age is the most obvious factor, since, in adopting a Piagetian point of view, we are accepting the assumption that maturation plays a part in cognitive growth. A large number of investigations have had as their main purpose, or a subsidiary one, the determination of the age at which formal operations begin to be used. Among these are studies by Renner and Stafford (1972), Bart (1971), Stephens, Mclaughlin, and Mahaney (1971) and Lovell (1961, 1968).

The results of these and other studies make it clear that only a minority of adolescents seem capable of, or find it necessary to, use this mode of thought. A few are able to solve Stage III A problems as early as 11 or 12, but most cannot solve truly formal operational problems until late in the teens or later, if at all. Studies which have included subjects well beyond adolescence (Higgens-Trenk and Gaite, 1971; Tomlinson-Keasey, 1972) have found that many adults cannot, or do not, use formal operations at all in the test situation. Piaget is aware that the ages he gave for the attainment of formal operations have not been corroborated by other investigators and that some persons never attain this level of intellectual development. He has suggested (Piaget, 1972) that this discrepancy may have occurred because his original work was carried out on pupils from better schools in Geneva and that subjects who have had less stimulating and cognitively nourishing environments may lag behind in development or never realize the possibilities which are inherent in all normal people.

The majority of high school students are probably not able to use formal operations except, perhaps, in a small number of situations. It is certainly a mistake to assume that even upper-level secondary students, except those who are very able, have access to formal operations for the solution of most problems.

2. The role of culture and education in promoting intellectural development has been the subject of several interesting studies. Greenfield (1966), in a study of schooled and unschooled children in Senegal, found that the pattern of conservation attainment was similar for both groups up to about nine years of age, after which the schooled children were markedly superior in logical thinking. Greenfield believes that her study suggests that, without schooling, no qualitative change in intellectual development occurs after about the age of nine

or ten. Goodnow and Bethon (1966) tested children in Hong Kong on three conservation tasks and on one task of combinatory reasoning and compared their performances with those of children in the United States. They found that the unschooled Hong Kong children performed as well as their American counterparts on the conservation tasks but that they could not perform the task of combinatorial reasoning. Peluffo (1967) compared the performance of adolescents who had recently moved from a rural area to an industrial Italian city with those who had grown up in the city on a test of combinatorial reasoning. He found that more of the city-bred children than the rural children could devise the necessary strategy (i.e., used formal operational thought) for the solution of the problem. Finally, Wozny and Cox (1973) compared suburban American youths, Puerto Rican youths who had grown up in the continental United States, and Puerto Rican youths who grown up on the Island on performance of four formal operationsl tasks. They found that the ages for successful performance of the tasks was 12-13 for the suburban youths, 14-15 for the Puerto Rican youths educated here, and 16-17 for the youths educated on the Island.

It is impossible to untangle the effects of culture and schooling. The type of education which young people receive is heavily dependent on the cultural milieu, the homes from which they come, and other imponderable factors. Nevertheless, it is evident that overall educational experience is an important factor in the growth of logical thinking. This has been explicitly recognized by Piaget (1972) who suggested that the reason for the age difference between the Geneva adolescents and others may be the superior quality of the schooling received by the Geneva youths. He also specualted that the different speeds of attainment of stages may be due to the "quality and frequency of intellectual stimulation received from adults or obtained from possibilities available to children for spontaneous activity in their environment." (p. 10).

Although the quality of schooling or educational environment has a marked effect on development of reasoning ability, inclusion of selected items or a program in the shcool curriculum has not been shown to be effective. Lovell (1961) found that his subjects did no better on formal operational tasks which formed a part of the curriculum than they did on other similar tasks and Teates (1970) found no differences in performance between students who had been in a special science program (ISCS) and those who had not.

4. Training or instruction on specidic tasks, on the other hand, has been shown to be effective in a number of experiments. This has come as something of a surprise because it has been found to be extremely difficult to teach concrete operational tasks and one might have supposed the same would be true for formal operational tasks.

In Bucharest, Fishbein, Pampu, and Minzat (1970) gave direct instruction to 60 subjects of ages 10, 12, and 14 on a formal operational task of combinary analyis and report that the instruction was effective in improving the students' ability to do the task. Tomlinson-Keasey (1972) tested six-grade girls, university women students, and middle-aged women on three tasks, followed this with training, posttesting immediately after training, and after an interval of one week. She found that the training produced increases in conceptual level on all three tasks but did not produce transfer to other tasks.

Brainerd and Allen (1971) carried out an experiment in which they used feedback and consecutive similar stimuli to train 10- and 11- children in density conservation. They report that "the training effect for density conservation is much larger than any previously reported training for concrete operations. ...and...the class of formal conservations may prove to be significantly more susceptible to training than the class of concrete conservations." (p.703). Their subjects were also able to transfer the density concept to another task. In another training experiment, Siegler, Liebert, and Liebert (1973) taught 10- and 11-year old boys to solve the pendulum problem through presentation of a conceptual framework, two analog problems, and a measurement instrument.

Methods of teaching formal operations have been studied in several experiments, Sheehan (1970) classified a sample of 60 students as concrete- or formal-operational, and assigned them at random to a concrete- or formal-operational training group. This made a 2x2 design, with one half of the concrete-level students receiving concrete-level training and the other half receiving formal-level training, one half of the formal-level students receiving concrete-level training and the other half receiving formal level training. The outcome was that formal operational students showed greater gains, regardless of mode of instruction, that achievement was more durable for formal-operational students, and that concrete-level instruction was more effective for all students Egan and Greeno (1973) compared the results of discovery and rule learning and interpreted their results as showing that in the discovery method, students assemble new material to existing structure and that in rule learning they acquire new structure.

The content or subject matter of the task has increasingly come to be recognized as a factor in the ability to solve problems. Lunzer (1973) has suggested and Stone and Ausubel (1969) have produced evidence that the structure of a problem may not be the determining factor in whether it will be solved. Piaget (1972) suggested the possibility that in life situations an adult might use formal operations in the area of his work and not in other areas.

5. A final factor which is being examined with increasing interest is reading ability and facility with language. The early work in formal operations ignored

reading ability but used analogies extensively with the apparent assumption that verbal analogies required only formal operational thought and had no language component. Furth has studied many aspects of the relationship of language to cognitive growth. About the formal period he wrote, "Verbal statements and propositions come into their own as primary nourishment of the child's intelligence as he is getting closer to formal operational functioning!" (Furth, 1970).

The following factors have been shown to be associated with intellectual development during adolescence: age, cultural and educational milieu, training in specific tasks, certain instructional methods, and, possibly, reading and language ability.

IMPLICATIONS FOR CURRICULUM AND METHODS IN SECONDARY SCIENCE

The present secondary science curriculum is based on the structure of science and to a large extent ignores the structure of the adolescent intellect. A major change in point of view will be required if science instruction is to promote intellectual growth for all, or evena majority, of secondary students.

One of the strongest impressions to emerge from reading the literature on formal operations is the vast differences between adolescents in intellectual achievement and ability. Instruction cannot possibly bring about learning unless it takes these differences into account. The high level of interest, even preoccupation, with the idea of Piagetian stages and the performance of certain tasks has obscured the overall thrust of Piaget's work and led to the notion that we have to wait until an adolescent becomes "formal operational" and then begin certain kinds of instruction. On the contrary, we should be devising instructional methods and promoting attitudes that will help students move forward from wherever they are. The literature comes through clearly on the point that intellectual development is gradual during adolescence, that there are important factors outside of the control of the school, but that the schools have an important role in this development.

Following are some of the implications of the literature which has been reviewed:

1. There is a wide divergence in ability to perform formal operational and other similar tasks. The need is for a program which will allow all adolescents to make progress in the development of reasoning ability.

2. Teachers should not wait for students to "become formal operational". It may never happen.

3. The ability to solve problems which require higher reasoning ability is not a sudden acquisition which will immediately generalize to other problems of the same logical structure. A student's cognitive operational level is likely to differ from subject matter to subject matter, particularly during the junior high school period.

4. Most instruction, especially that below the junior year, should be in a concrete operational mode. This does <u>not</u> mean that it should all take place in the laboratory, but that problems should be posed in concrete terms, approached from different angles, and that students should be engaged directly with the content. The aim is the transformation of overt action into mental operations, the building of a mental structure which can assimilate new concepts and, eventually, think in abstractions and generalizations.

5. The content of a problem may be more important than the structure of the problem. The wisdom of trying to teach disembodied "processess of science", without regard to content should be given another look.

6. Much more needs to be known about the relation of reading and language ability to intellectual development beyond childhood.

7. We need much more knowledge of the details of how important concepts are acquired (the fine structure of task or concept acquisition).

Finally, we might consider how useful or productive it is to think solely in terms of formal operations and Piaget tasks in considering adolescent cognitive growth. The four-square box of formal logic seems too tight and constricting a container for the broad range of reasoning powers which are possible.

REFERENCES

1. Adler, I. Mental growth and the art of teaching. The Mathematics Teacher. 1966, 59, 706-715.

2. Berzonsky, M. Interdependence of Inhelder's and Piaget's model of logical thinking. Developmental Psychology. 1968, 4 (3), 469-76.

3. Brainerd, C. The construction of the formal operations of implication reasoning and proportionality in children and adolescents. Doctoral Dissertaion, Michigan State University, 1970.

4. Allen, T. Training and generalization of density conservation: effects of feedback and consecutive similar stimuli. Child Development. 1971, 42, 693-704.

5. Bynum, T., Thomas, J. and Weitz L. Truth functional logic in formal operational thinking: Inhelder and Piaget's evidence. Developmental Psychology, 1972, 7 (2) 129-32.

6. Egan, D. and Greeno, J. Acquiring cognitive structure by discovery and rule learning. Journal of Educational Psychology, 1973, 64 (1), 85-87.

7. Fishbein, E., Pampu, I. and Minzat, I. Effects of age and instruction on combinatory ability in children. British Journal of Educational Psychology. 1970, 40, 261-270.

8. Furth, N. Piaget for Teachers. Englewood Cliffs, N.J.: Prentice-Hall, 1970.

9. ______, Piaget, IQ, and the nature-nurture controversy. Human Development. 1973, 16, 61-73.

10. Falvell, J. and Wohlwill, J. Formal and functional aspects of cognitive growth in Elkind, D. and Falvell J. (Eds) Studies in Cognitive Growth. New York: Oxford Press, 1969.

11. Greenfield, P. On culture and conservation. In Bruner, J., Olver, R. and Greenfield, P. Studies in Cognitive Growth. New York: Wiley.

12. Goodnow, J. and Bethon, G. Piaget's tasks: the effects of schooling and intelligence. Child Development, 1966, 37, 573-582.

13. Higgins-Trenk, A. and Gaite, A. Elusiveness of formal operational thought in adolescents. Proceedings of American Psychological Association. 1971, 201-202.

14. Kessen, W. "Stage" and "structure" in the study of children. Cognitive Development in Children. Five Monographs of the Society for Research in Child Development. Chicago: University of Chicago Press, 1970.

15. Lovell, K. A follow-up study of Inhelder and Piaget's the growth of logical thinking. British Journal of Psychology. 1961, 52, 143-153.

16. ______. The growth of basic mathematical and scientific concepts in children. London . University of London,(3rd Edition) 1964.

17. ______. Developmental processes in thought. Journal of Experimental Education, 1968, 37, (1), 15-21.

18. ______, and Ogilvie, E. The growth of the concept of volume in junior school children. Journal of Child Psychology and Psychiatry. 1961, 2, 118-126.

19. Lunzer, E. Some points of Piagetian theory in the light of experimental criticism. Journal of Child Psychology and Psychiatry. 1960, 1, 191-202.

20. ______, Problems of formal reasoning in test situations. In Cognitive Development in Children. Chicago: University of Chicago Press. 1970 (first published 1965)

21. ______, Address to Jean Piaget Society. Philadelphia, May, 1973 (on tape).

22. Parson, C. Inhelder and Piaget's the growth of logical thinking, II - a logician's viewpoint. British Journal of Psychology. 1960, 51 (1), 75-84.

23. Peel, E. The nature of adolescent judgment. New York: Wiley - Interscience, 1971.

24. Peluffo, N. Culture and cognitive problems. International Journal of Psychology, 1967, 2, 187-198.

25. Piaget, J. and Inhelder, B. The growth of logical thinking from childhood to adolescents. New York: Basic Books, 1958.

26. ______, and Szeminska, A. The child's conception of geometry. London: Routledge and Kegan Paul, 1952.

27. Pinard, A. and Laurendeau, M. "Stage" in Piaget's cognitive - developmental theory: exegesis of a concept. in Elkind, D. and Falvell, J. (Eds.) Studies in Cognitive Growth. New York: Oxford Press. 1969.

28. Renner, J. and Stafford, D. Teaching science in the secondary school. New York: Harper and Row, 1972.

29. Seigler, R., Liebert, D. and Liebert, R. Inhelder and Piaget's Pendulum problem: teaching preadolescents to act as scientists. Developmental Psychology. 1973, 9 (1), 97-101.

30. Sheehan, D. J. The effectiveness of concrete and formal instructional procedures with concrete and formal-operational students. Doctoral dissertation. 1970, State University at Albany.

31. Stephens, B., McLaughlin, J. and Mahaney, E. Ages at which Piagetian concepts are achieved. Proceedings of the American Psychological Association. 1971, 203-204.

32. Stone, M. A. and Ausubel, D. The intersituational generality of formal thought. Journal of Genetic Psychology. 1969, 115, 169-180.

33. Teates, T. A comparison of the performance of ISCS and non-ISCS ninth-grade science students on several Piaget-type tasks. Doctoral dissertation, Florida State University, 1970.

34. Tomlinson-Keasey, C. formal operations in females from 11 to 54 years of age. Developmental Psychology. 1972, 6 (2) 364.

35. Wozny, C. and Cox, D. The effects of culture and education on the acquisition of formal operational thinking. Paper delivered at annual meeting of American Educational Research Association, New Orleans, 1973.